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(54) **INCREASING BOREHOLE WALL PERMEABILITY TO FACILITATE FLUID SAMPLING**

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(58) **Field of Classification Search**
CPC E21B 49/10; E21B 43/119; E21B 43/11; E21B 47/00
See application file for complete search history.

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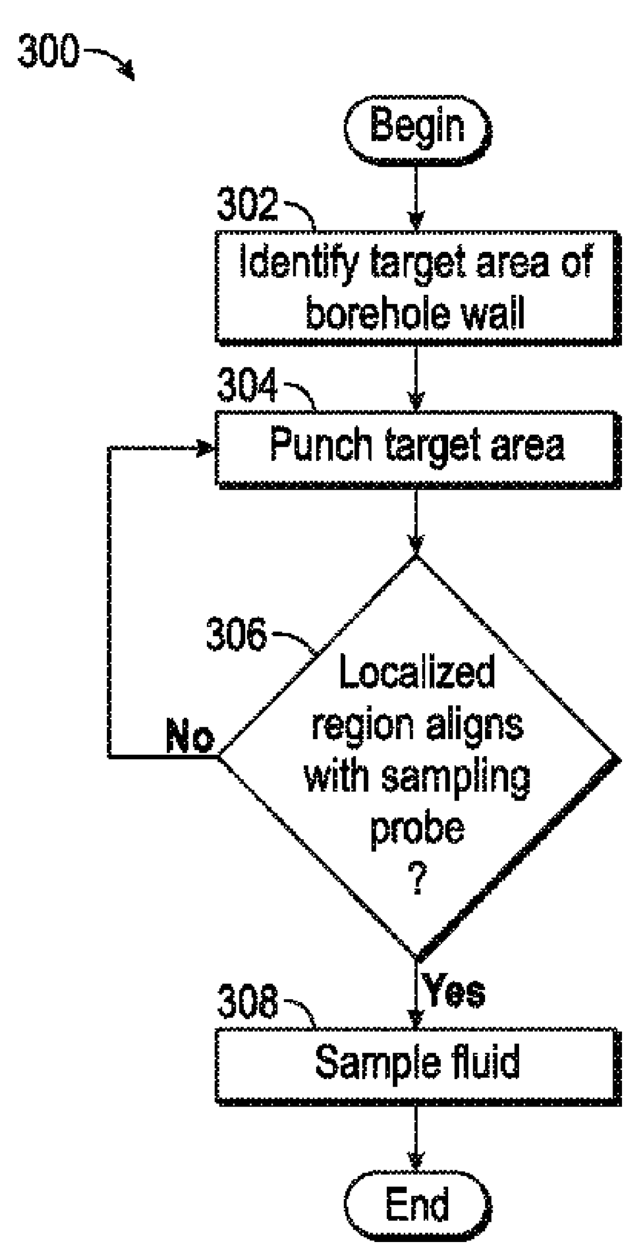
(57) **ABSTRACT**

A drill string tool assembly, in some embodiments, comprises a punching tool that induces fissures to increase permeability in a localized region of a borehole wall. The assembly also comprises a sensor that detects spatial features of the fissures and processing logic, coupled to the sensor and punching tool, that adapts operation of the punching tool based on the spatial features. The assembly further comprises a fluid sampling probe, coupled to the processing logic, that samples fluid from the localized region.

20 Claims, 8 Drawing Sheets



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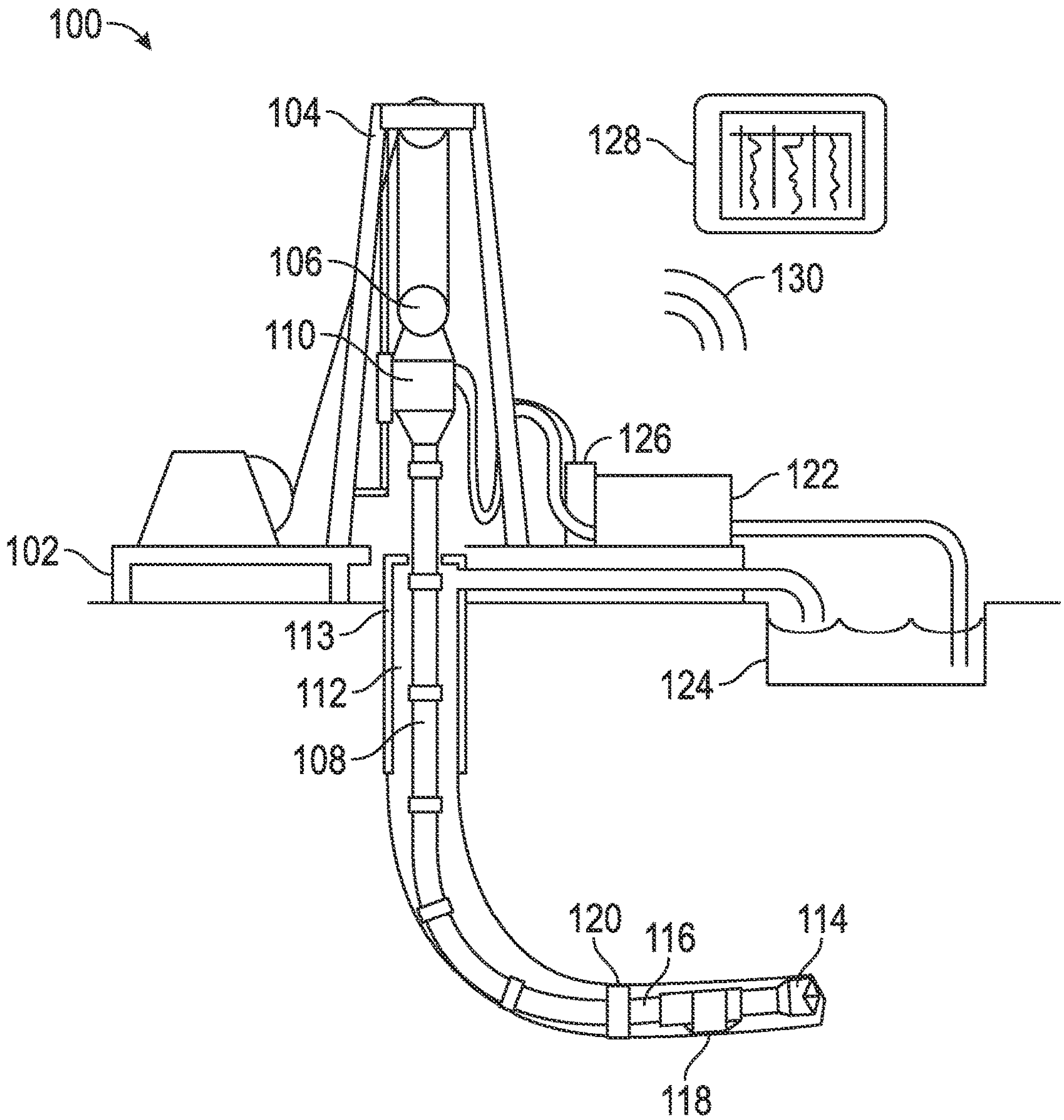
100
104
128
106
130
110
126
122
102
113
124
112
108
120
116
114
118

FIG. 1

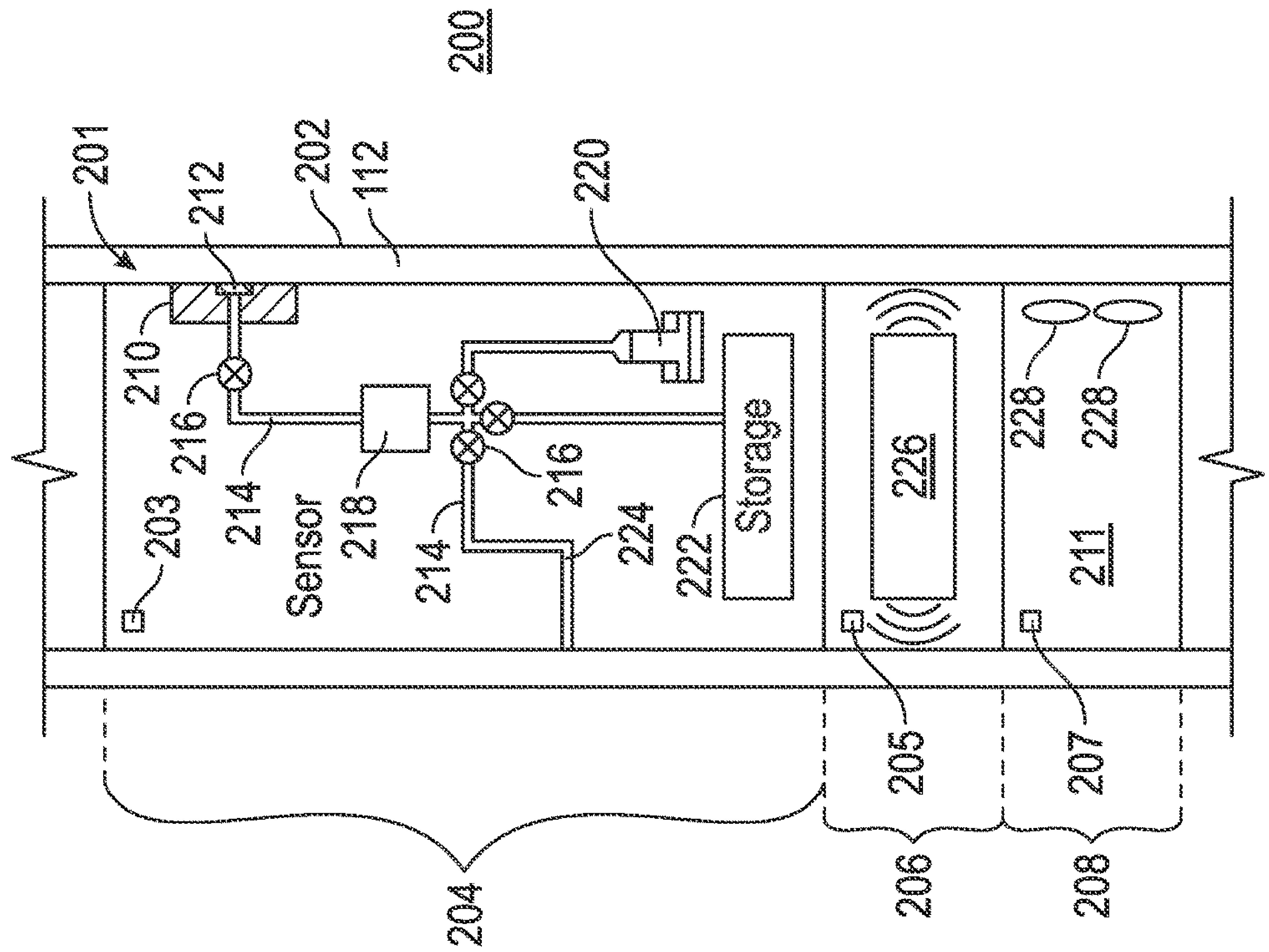
200
201
202
112
212
210
220
216
214
203
Sensor
218
216
214
224
222
Storage
226
228
228
211
205
207
204
206
208

FIG. 2

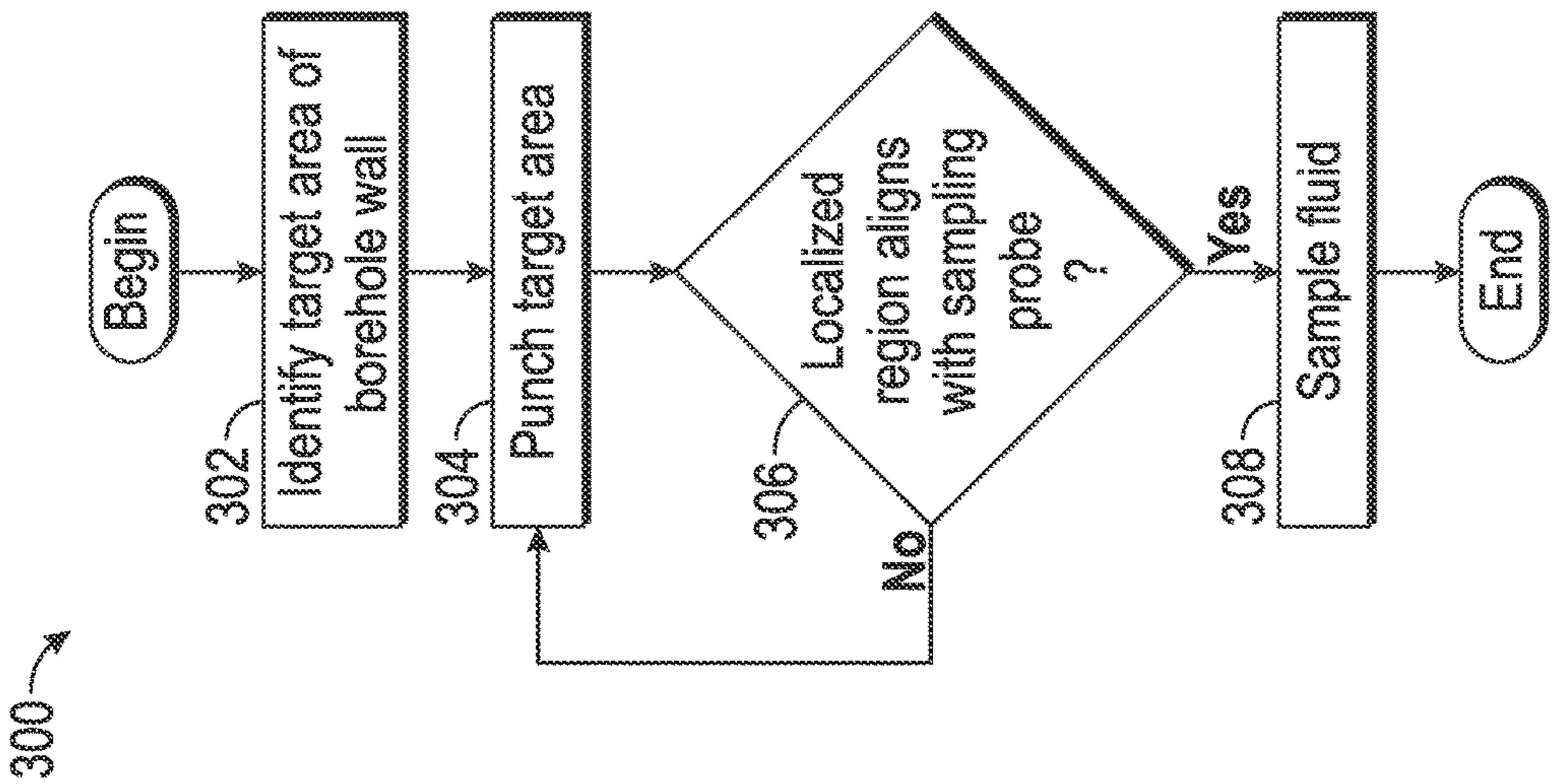
300
Begin
302
Identify target area of borehole wall
304
Punch target area
306
Localized region aligns with sampling probe ?
No
Yes
308
Sample fluid
End

FIG. 3A

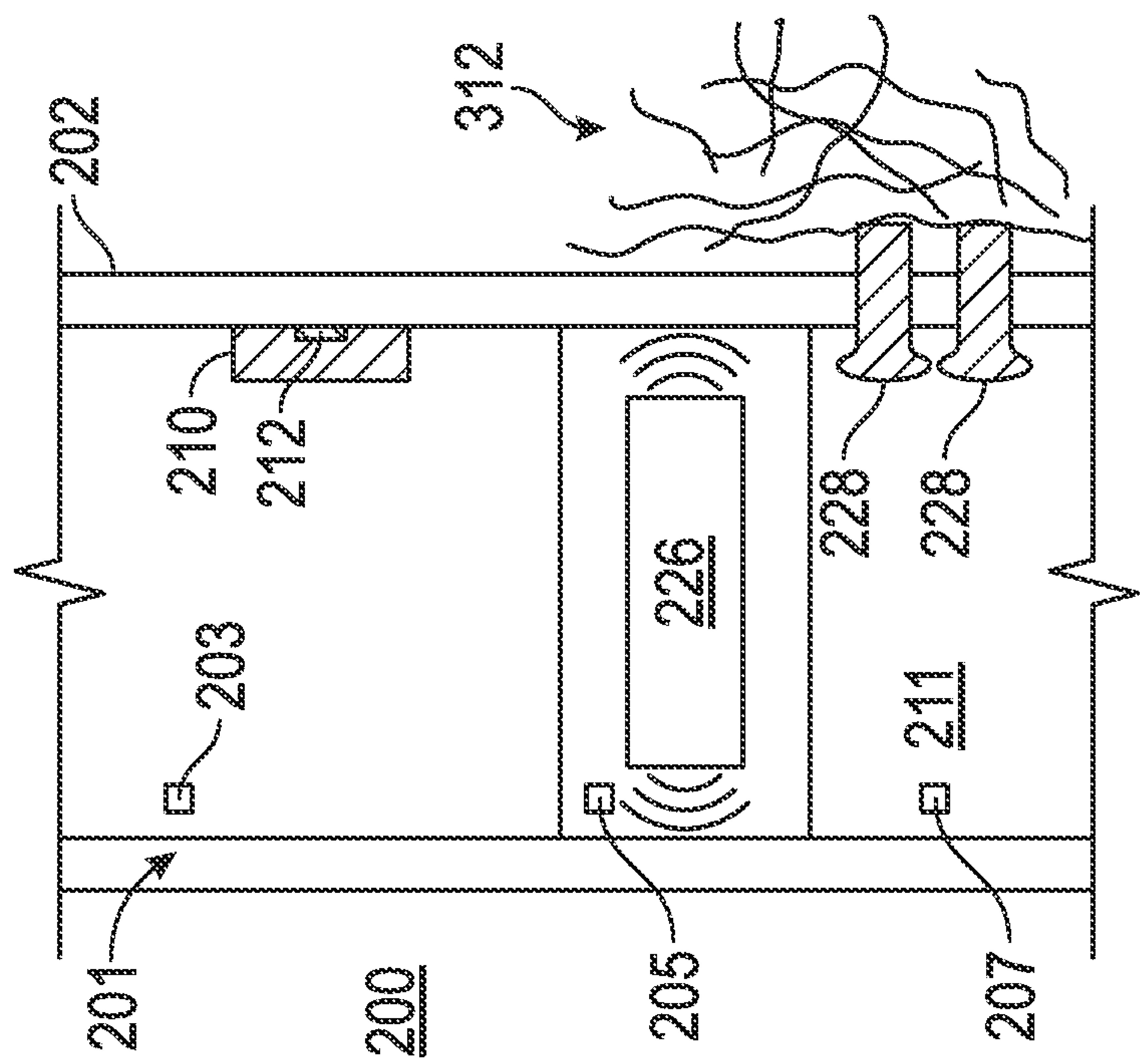
202
312
210
212
203
226
228
228
211
201
200
205
207

FIG. 3C

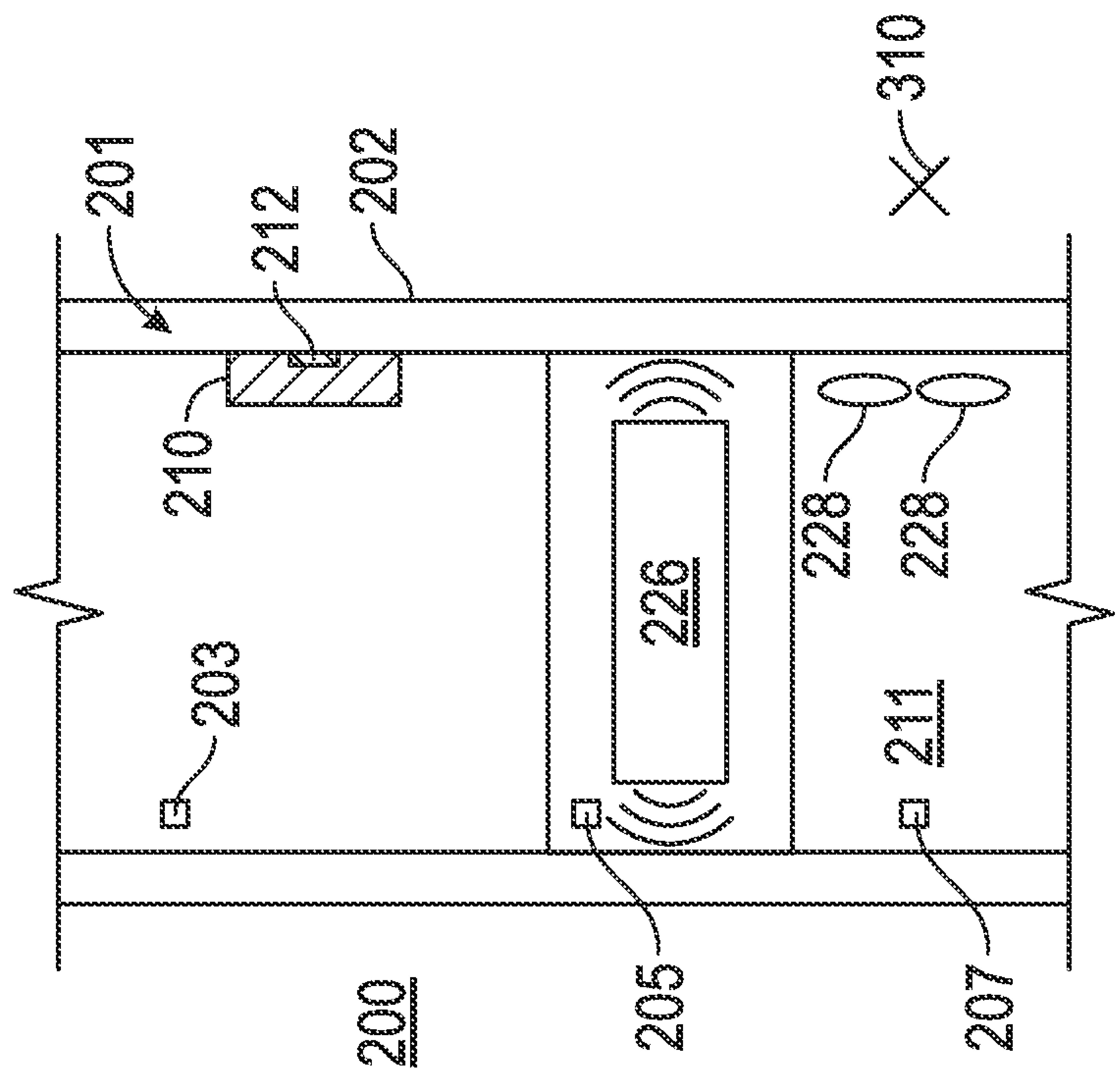
201
212
202
310
210
203
226
228
228
211
200
205
207

FIG. 3B

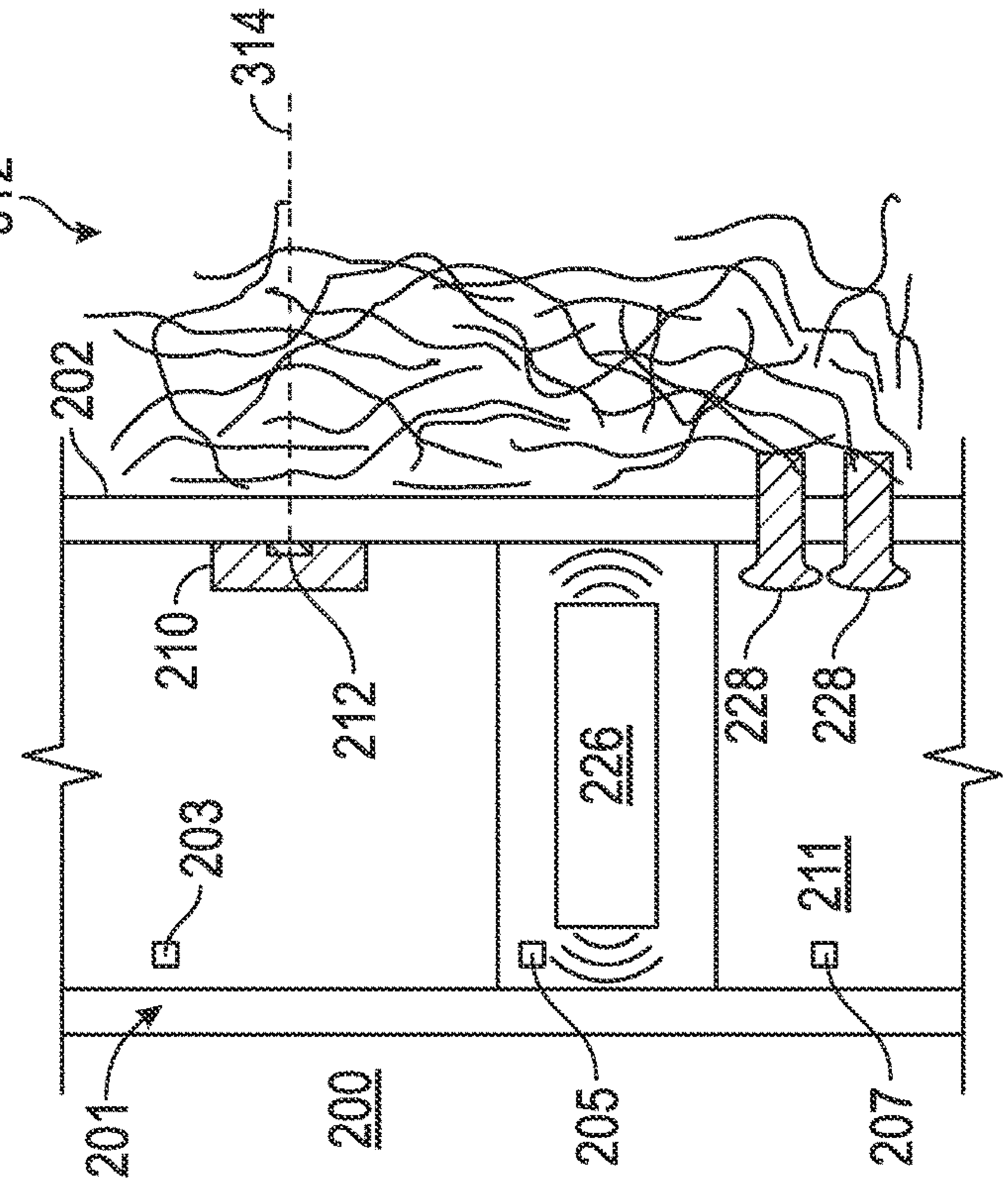
312
314
202
210
212
226
228
228
203
211
201
200
205
207

FIG. 3E

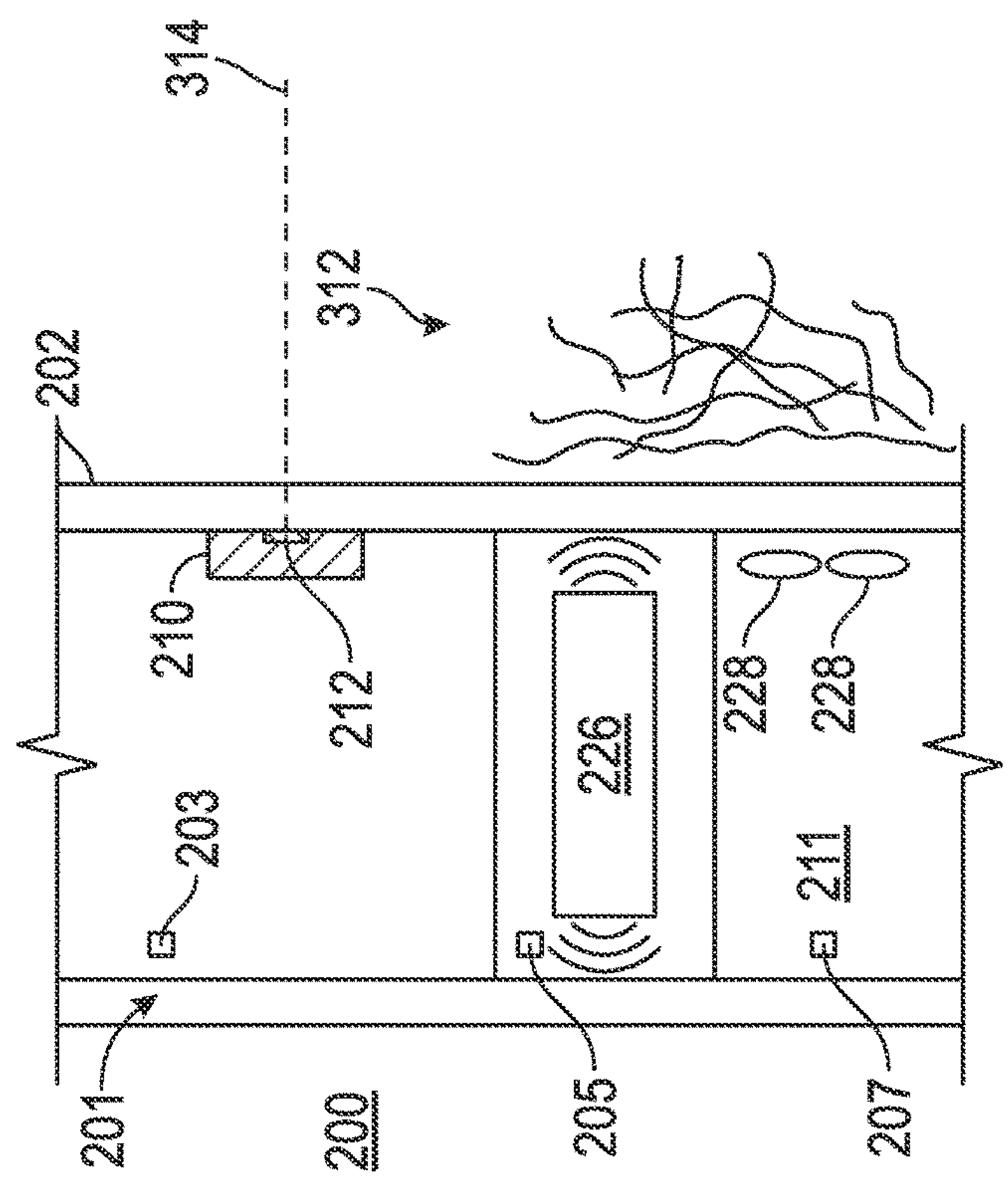
314
312
202
210
212
226
228
228
203
211
201
200
205
207

FIG. 3D

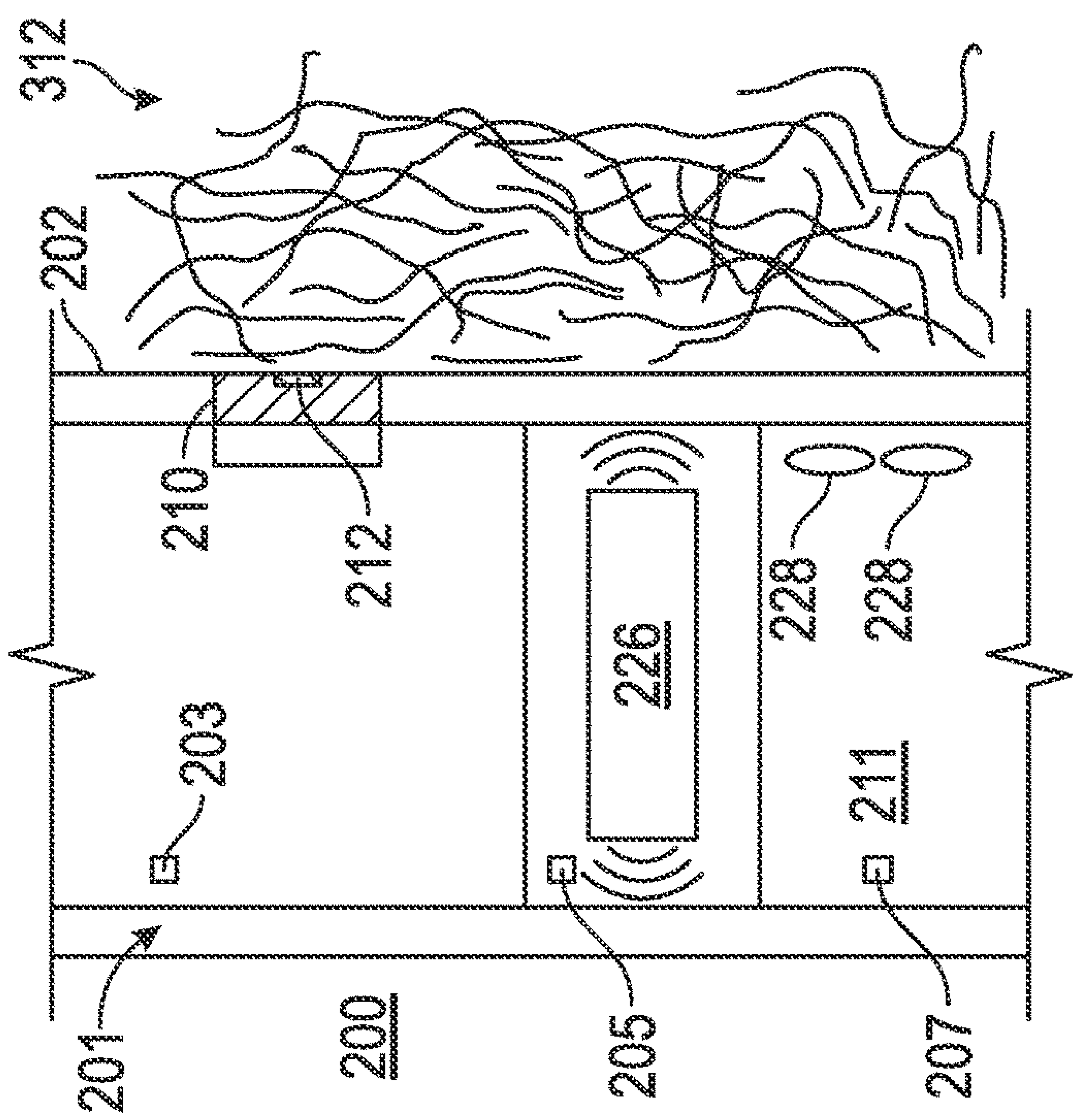
312
202
210
212
228
228
203
226
211
201
200
205
207

FIG. 3F

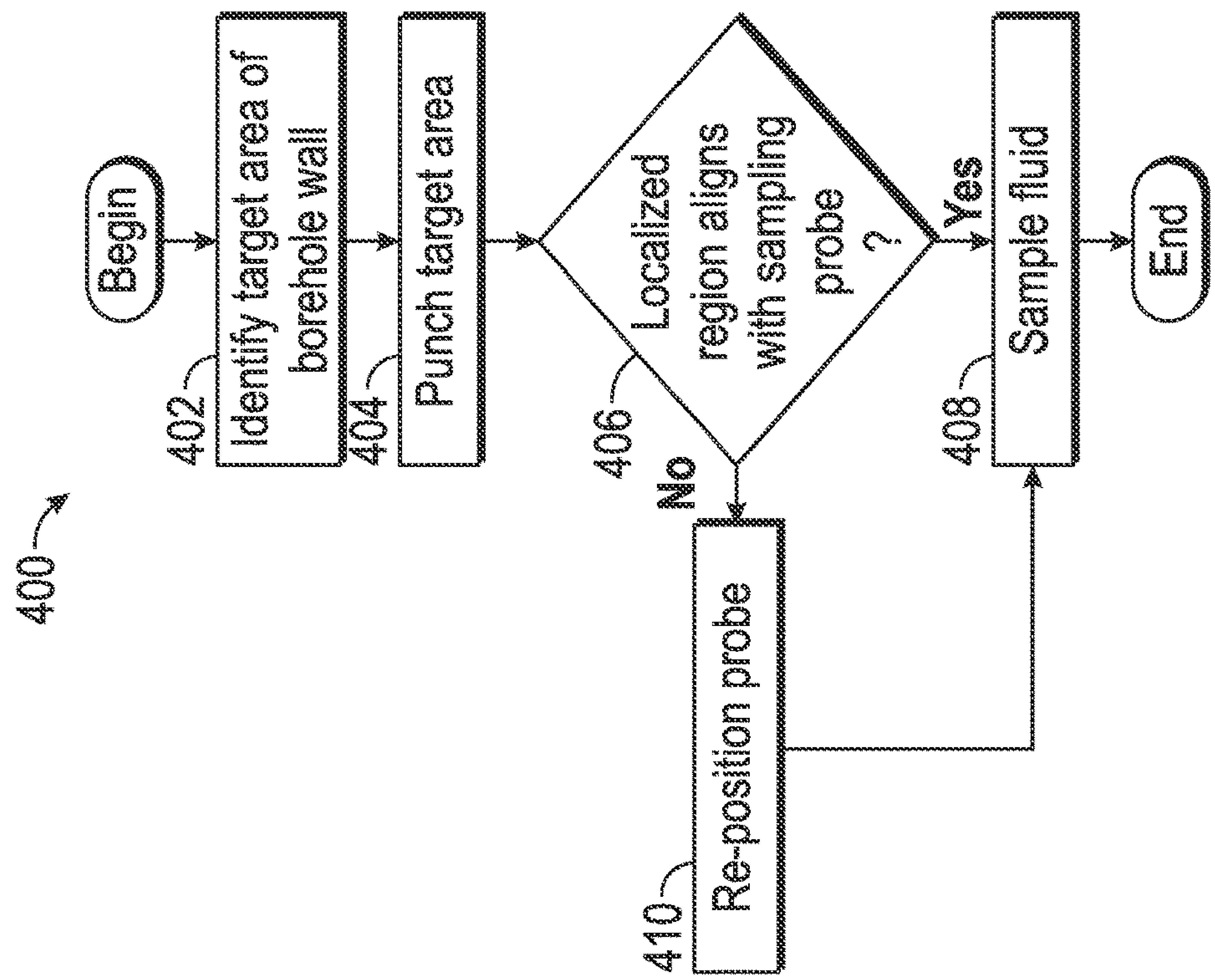
400
Begin
402
Identify target area of borehole wall
404
Punch target area
406
Localized region aligns with sampling probe ?
No
Yes
410
Re-position probe
408
Sample fluid
End

FIG. 4A

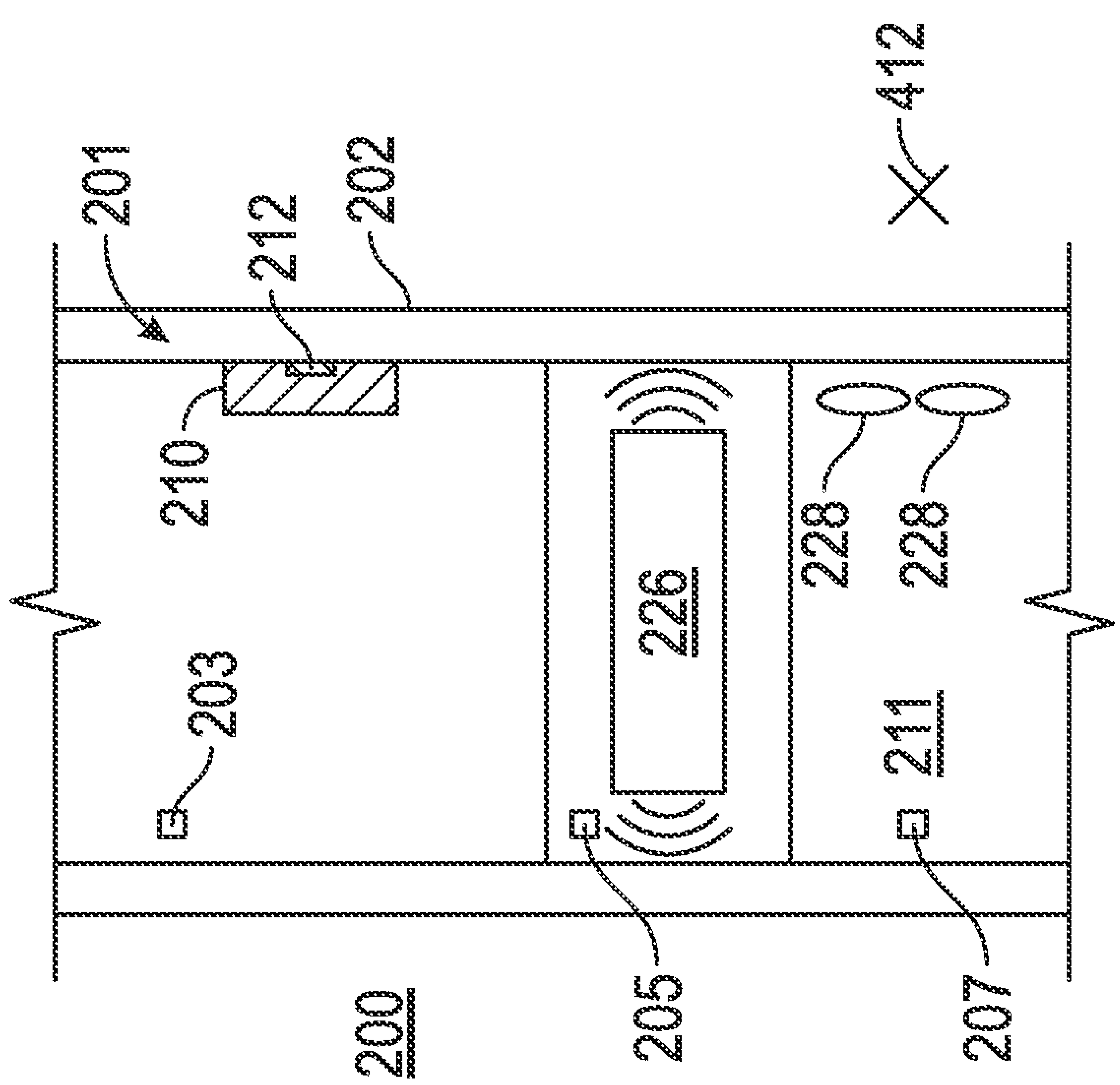
201
212
202
412
210
226
228
228
203
211
200
205
207

FIG. 4B

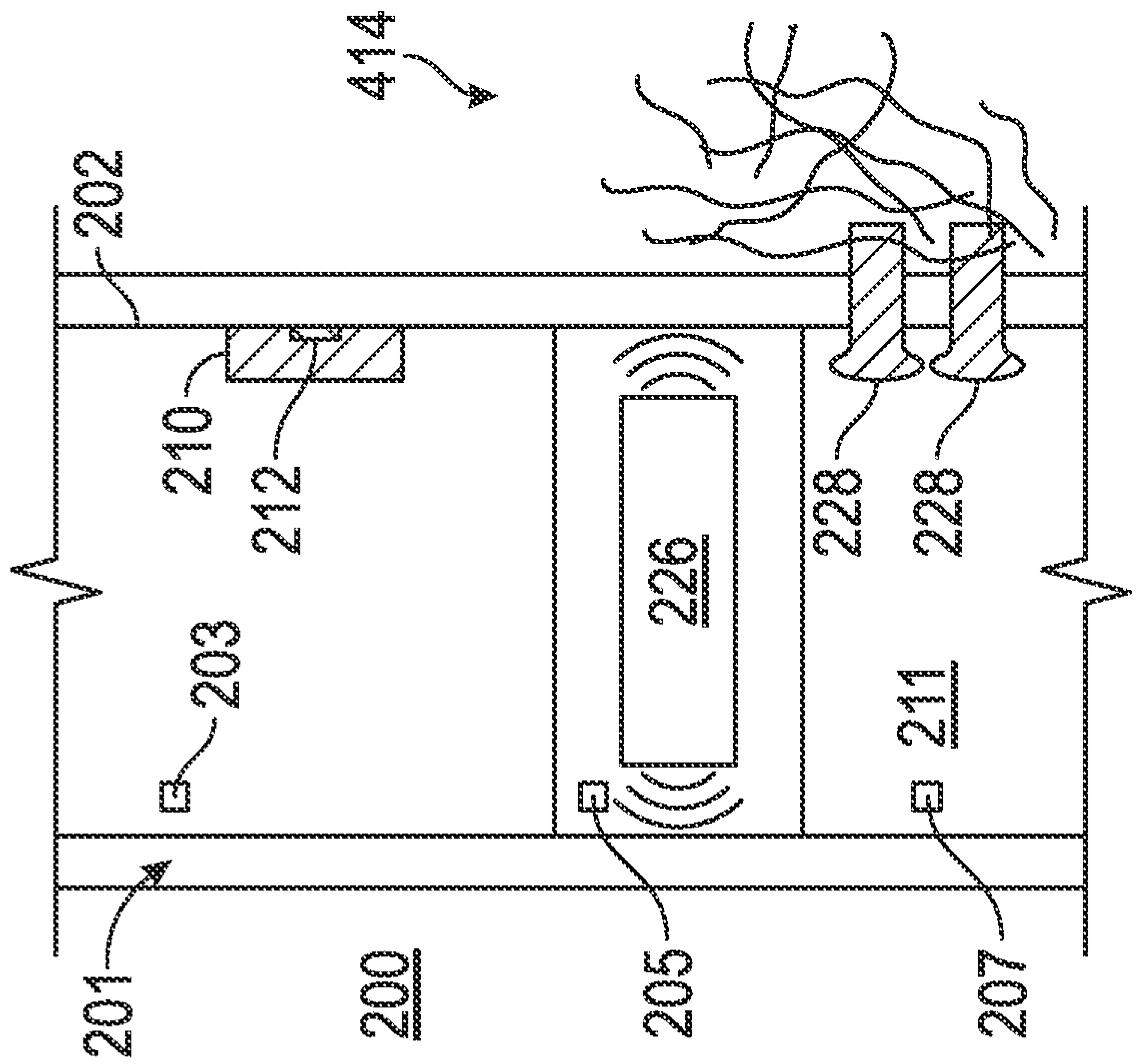
202
414
210
212
226
228
228
203
211
201
200
205
207

FIG. 4C

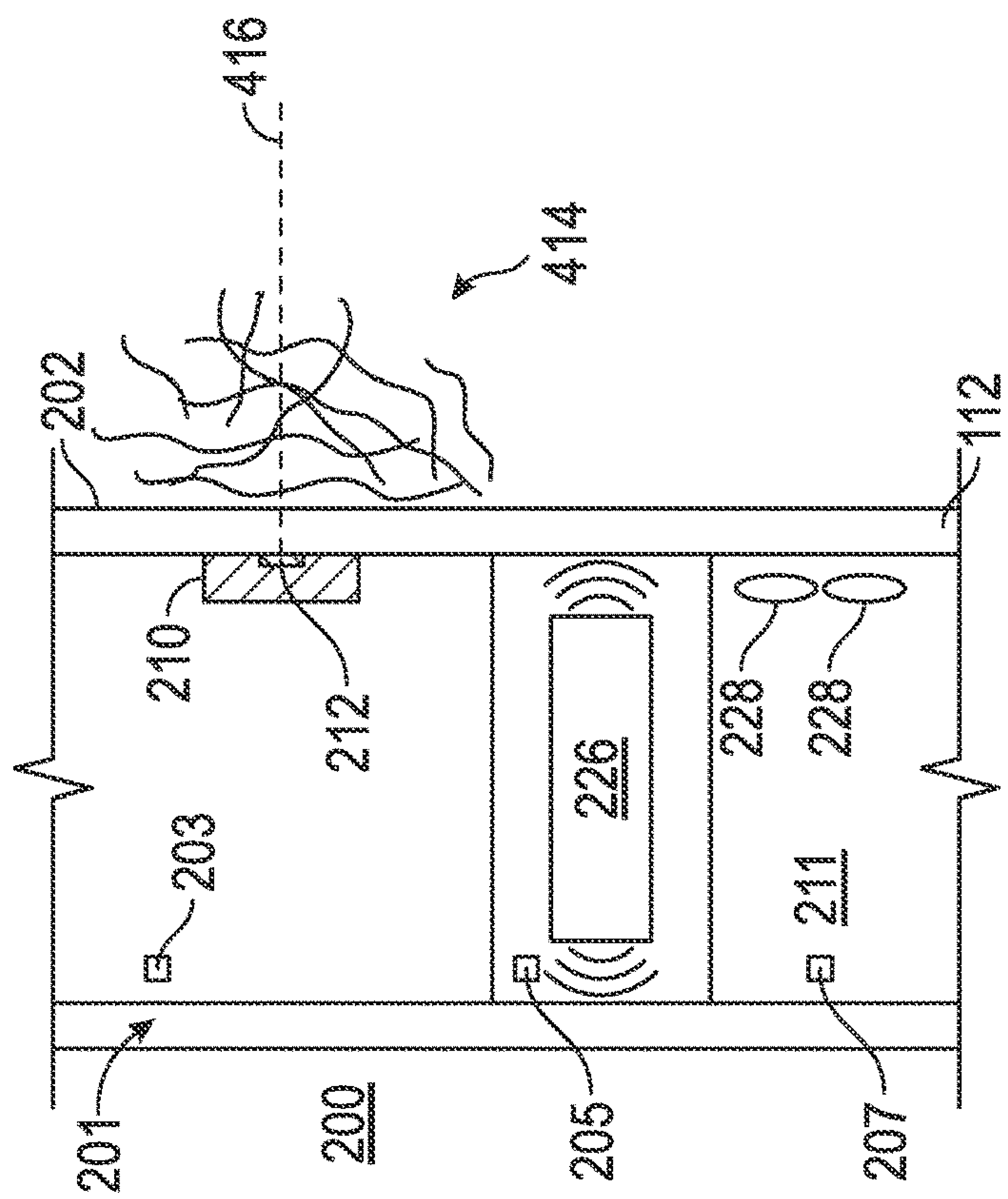
416
414
202
112
210
212
203
226
228
228
211
201
200
205
207

FIG. 4E

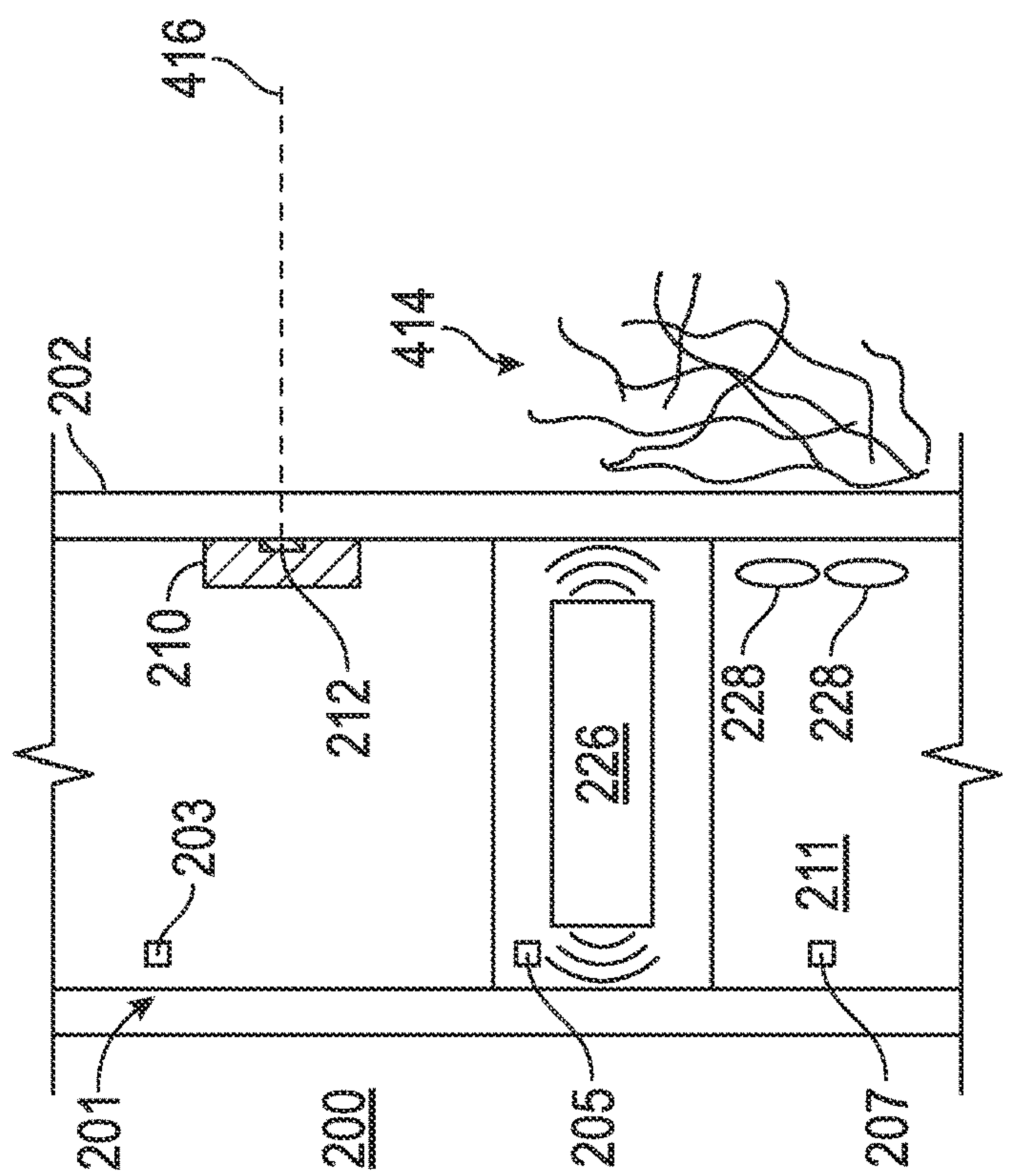
416
414
202
210
212
203
226
228
228
211
201
200
205
207

FIG. 4D

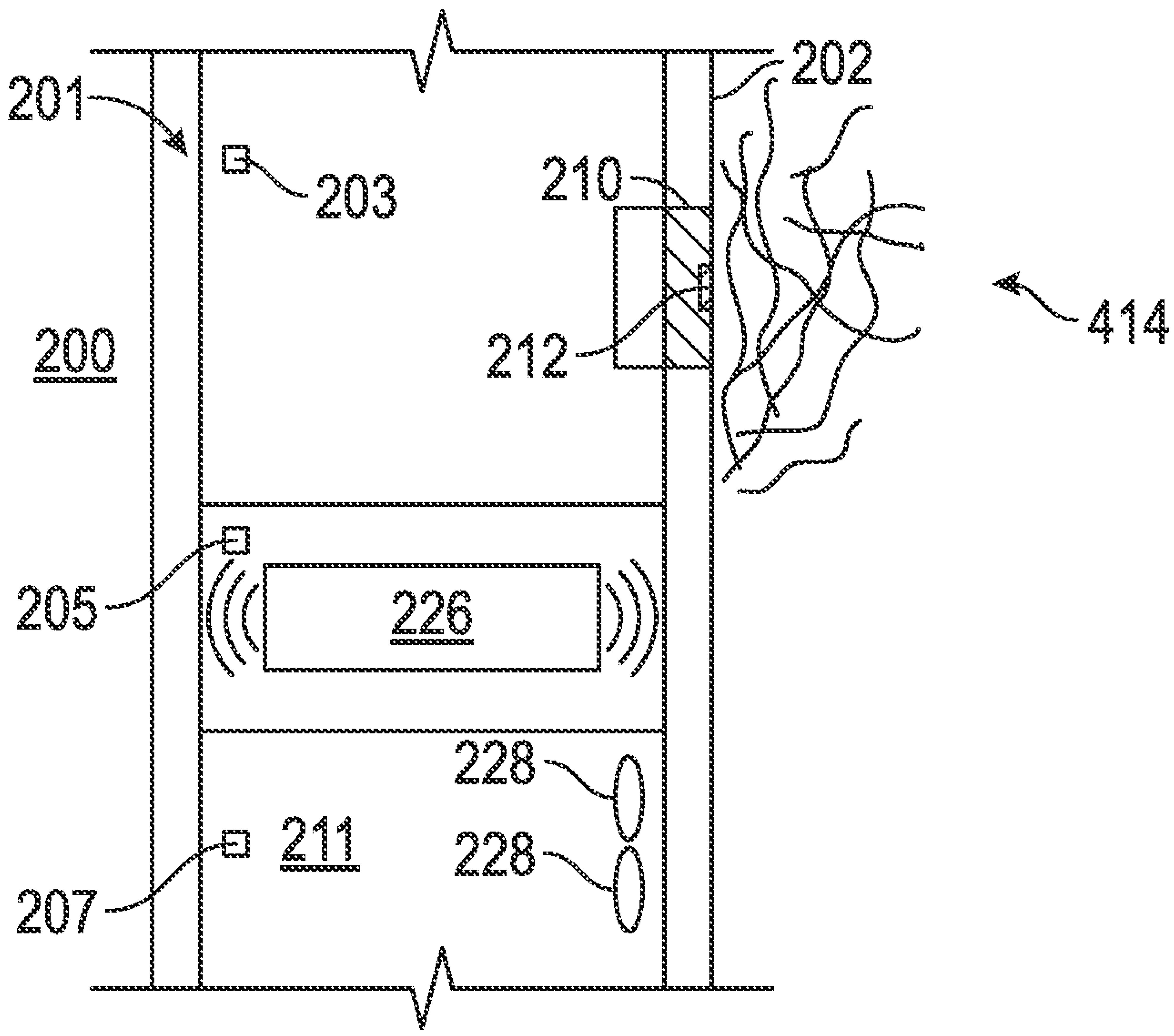

FIG. 4F

INCREASING BOREHOLE WALL PERMEABILITY TO FACILITATE FLUID SAMPLING

BACKGROUND

Subsurface formations contain reservoir fluid which, when sampled and analyzed, may provide useful information about the formation. For example, fluid analysis results can be used to perform reservoir correlations and simulations and to optimize wellbore placement and generate production forecasts. Fluid is typically sampled using a probe that is extended from a downhole tool assembly and pressed against a borehole wall. Ideally, when a probe is pressed against an area of a formation that is highly permeable, fluid is pumped out from the formation and into the probe. Low permeability areas of a formation, however, make fluid flow and collection difficult.

BRIEF DESCRIPTION OF THE DRAWINGS

Accordingly, there are disclosed in the accompanying drawings and in the following description methods and systems for increasing borehole wall permeability to facilitate fluid sampling. In the drawings:

FIG. **1** is a schematic view of an illustrative drilling environment, in accordance with embodiments;

FIG. **2** is a schematic view of an illustrative drill string tool assembly, in accordance with embodiments;

FIG. **3**A is a flow diagram of an illustrative method for increasing the permeability of a borehole wall, in accordance with embodiments;

FIGS. **3**B-**3**F are schematic views of an illustrative drill string tool assembly performing the method of FIG. **3**A, in accordance with embodiments;

FIG. **4**A is a flow diagram of another illustrative method for increasing the permeability of a borehole wall, in accordance with embodiments; and

FIGS. **4**B-**4**F are schematic views of an illustrative drill string tool assembly performing the method of FIG. **4**A, in accordance with embodiments.

DETAILED DESCRIPTION

The methods and systems disclosed herein entail the use of a punching tool to punch a target area of a borehole wall, thereby inducing and/or enhancing fissures throughout a localized region. These fissures increase the permeability of the localized region. The methods and systems further comprise repositioning the drill string tool assembly until a fluid sampling probe aligns with the fissured, localized region and extending the probe toward the localized region to sample fluid. Alternatively, in lieu of repositioning the tool assembly, the methods and systems comprise punching the localized region until the fissured, localized region is aligned with the fluid sampling probe. The probe is then extended for sampling.

FIG. **1** is a schematic view of an illustrative drilling environment **100** in which the systems and methods disclosed herein may be implemented. The drilling environment **100** comprises a drilling platform **102** that supports a derrick **104** having a traveling block **106** for raising and lowering a drill string **108**. A top-drive motor **110** (or, in other embodiments, a rotary table) supports and turns the drill string **108** as it is lowered into the borehole **112**. The drill string's rotation, alone or in combination with the operation of a downhole motor, drives the drill bit **114** to

extend the borehole. The drill bit **114** is one component of a bottomhole assembly (BHA) **116** that may further include a rotary steering system (RSS) **118** and stabilizer **120** (or some other form of steering assembly) along with drill collars and logging instruments. A pump **122** circulates drilling fluid through a feed pipe to the top drive **110**, downhole through the interior of drill string **108**, through nozzles in the drill bit **114**, back to the surface via the annulus around the drill string **108**, and into a retention pit **124**. The drilling fluid transports drill cuttings from the borehole **112** into the retention pit **124** and aids in maintaining the integrity of the borehole. An upper portion of the borehole **112** is stabilized with a casing string **113** and the lower portion being drilled is an open (uncased) borehole.

The drill collars in the BHA **116** are typically thick-walled steel pipe sections that provide weight and rigidity for the drilling process. The thick walls are also convenient sites for installing logging instruments that measure downhole conditions, various drilling parameters, and characteristics of the formations penetrated by the borehole. The BHA **116** typically further includes a navigation tool having instruments for measuring tool orientation (e.g., multi-component magnetometers and accelerometers), depth and a control sub with a telemetry transmitter and receiver. The control sub coordinates the operation of the various logging instruments, steering mechanisms, and drilling motors, in accordance with commands received from the surface, and provides a stream of telemetry data to the surface as needed to communicate relevant measurements and status information. A corresponding telemetry receiver and transmitter is located on or near the drilling platform **102** to complete the telemetry link. The most widely used telemetry link is based on modulating the flow of drilling fluid to create pressure pulses that propagate along the drill string ("mud-pulse telemetry or MPT"), but other known telemetry techniques are suitable. Much of the data obtained by the control sub may be stored in memory for later retrieval, e.g., when the BHA **116** physically returns to the surface.

A surface interface **126** serves as a hub for communicating via the telemetry link and for communicating with the various sensors and control mechanisms on the platform **102**. A data processing unit (shown in FIG. **1** as a tablet computer **128**) communicates with the surface interface **126** via a wired or wireless link **130**, collecting and processing measurement data to generate logs and other visual representations of the acquired data and the derived models to facilitate analysis by a user. The data processing unit may take many suitable forms, including one or more of: an embedded processor, a desktop computer, a laptop computer, a central processing facility, and a virtual computer in the cloud. In each case, software on a non-transitory information storage medium may configure the processing unit to carry out the desired processing, modeling, and display generation.

FIG. **2** is a schematic view of an illustrative drill string tool assembly **201** in accordance with embodiments. The assembly **201** is disposed within the borehole **112**, which is formed in the formation **200**. The assembly **201** comprises multiple subs **204**, **206** and **208**. Sub **204** houses a fluid sampling system comprising a cup-shaped sealing pad **210**, a fluid sampling probe **212**, flow lines **214**, valves **216**, a fluid density sensor **218**, a piston pump **220**, a multi-chamber fluid sample storage **222**, fluid exhaust **224**, spatial feature sensor **226**, and punching tool **211**. In some embodiments, the aforementioned control sub communicates directly with and controls equipment housed in each of the subs **204**, **206** and **208**. In other embodiments, each sub houses a separate processing logic **203**, **205** or **207** that controls the equipment within that sub. In such embodiments, the processing logic in each sub may communicate directly or indirectly with the control sub, with processing logic or equipment in other subs, and/or with the processing unit (e.g., tablet computer **128**). Regardless of the precise configuration of the processing logic and the control sub, some or all of the hardware and/or software used to control the systems and perform the methods described herein are collectively referred to as "processing logic." Additionally, although the drawings show the fluid sampling system, spatial feature sensor **226** and punching tool **211** being distributed among multiple subs, in some embodiments, the equipment may be housed within a single sub.

When triggered, the punching tool **211** induces fissures in a localized region of the borehole wall **202**. As used herein, the term "localized region" refers to an area of a formation that experiences an increase in permeability as a result of one or more punches by the punching tool **211**. In some embodiments, the punching tool **211** comprises a perforating gun. In such embodiments, the punching tool **211** comprises gun charges **228** that produce controlled explosions to punch the borehole wall **202**. In some embodiments, the gun charges **228** are physically oriented with a zero degree gun phasing, meaning that in vertical boreholes, all charges **228** are vertically aligned along the length of the tool assembly **201**, and in horizontal boreholes, all charges are horizontally aligned along the length of the tool assembly **201**. The gun charges **228** may be phased in any manner suitable for punching the formation **200**. The punching tool **211** may alternatively comprise a laser, a steam or fluid jet, a heating device, a hammer, a hydraulic ram or any other suitable device.

The spatial feature sensor **226** detects fissures and their spatial features, such as length, width, height, position, direction, concentration, total number, average volume, and/or total volume. Thus, the spatial feature sensor **226** is able to detect and characterize fissures induced by the punching tool **211** and helps to determine whether a localized region of the formation has been adequately fissured for fluid sampling purposes. In some embodiments, the spatial feature sensor **226** comprises a fiber optics sensor. Other types of sensors, such as electromagnetic sensors, also may be used. Ultrasonic and microwave echo transducers may be employed to measure fine features associated with the presence of fissures. NMR tools can similarly detect fissure presence and size. Larger-scale features associated with fissures may be monitored using resistivity sensors and sonic velocity sensors.

In operation, the sealing pad **210** and fluid sampling probe **212** extend away from the tool assembly **201** to make contact with the area of the formation **200**—and, more particularly, borehole wall **202**—from which fluid is to be sampled. Once the sealing pad **210** makes contact with the borehole wall **202** and forms a seal with the wall, the piston pump **220**—which couples with the fluid sampling probe **212**—forms a pressure differential and pumps formation fluid in from the formation via the probe **212**. With the cooperation of an arrangement of valves **216**, the piston pump **220** regulates a flow of various fluids in and out of the formation sampling system via the flow lines **214**. The fluid density sensor **218** measures the density of fluid flowing through the flow lines **214**. The sensor **218** identifies formation fluid that is contaminated (e.g., by borehole fluid seeping into highly permeable areas of the borehole wall **202**), and such contaminated fluid is exhausted to the borehole **112** via the fluid exhaust **224**. Once the flow of formation fluid reaches a steady state density, it is routed to the storage **222** for collection.

FIG. **3**A is a flow diagram of an illustrative method **300** for increasing the permeability of a borehole wall. Processing logic (e.g., one or more of processing logic **203**, **205** and/or **207**) performs the method **300** during a drilling process, meaning that the steps of method **300** may be performed when the drill bit **114** (FIG. **1**) is operational, during periods when the drill bit **114** is temporarily stopped, or both. Method **300** is now described in light of FIGS. **3**B-**3**F, which constitute an illustrative implementation of the method **300**. The method **300** comprises identifying a target area of a borehole wall from which formation fluid is to be extracted (step **302**). The target area may be identified by drilling personnel considering various factors, such as target area depth and permeability based on surface logs, adjacent well logs and other relevant data. FIG. **3**B illustrates this step and denotes the target area of the formation with numeral **310**. As shown, the punching tool **211**—and, in particular, gun charges **228**—are in proximity to the target area **310**.

The method **300** then comprises punching the target area **310** using the punching tool **211** (step **304**). The precise technique by which the target area is punched varies according to the punching tool **211** used. In the embodiment illustrated in FIG. **3**C, punching is performed using perforation gun charges **228**, as shown. The punch induces fissures in localized region **312**, thereby increasing the permeability of the region **312**. As explained, the localized region **312** is a region in the formation **200** that experiences an increase in permeability due to punches by the punching tool **211**.

The method **300** also comprises determining whether the localized region—i.e., the region of the formation that has increased permeability as a result of the punching in step **304**—aligns with the fluid sampling probe (step **306**). A localized region is aligned with the fluid sampling probe if a plane of the fluid sampling probe that is orthogonal to the axis of the tool assembly coincides with the localized region. In addition, in some embodiments, whether a probe and a localized region are aligned depends on whether one or more fissures in the localized region are sufficiently close to the borehole wall **202** so that the fluid is accessible to the sampling probe. Sensor **226** performs this detection step **306** using any of a variety of known techniques to identify the spatial features of the fissures (e.g., length, width, height, position, direction, concentration, total number, average volume, and/or total volume) in the localized region **312**. As dashed line **314** indicates in FIG. **3**D, the fluid sampling probe **212** does not align with the localized region **312**. Specifically, the localized region **312** is farther downhole than the fluid sampling probe **212**. Thus, were the probe **212** extended to the formation **200**, it would not benefit from the increased permeability of localized region **312**.

If the result of the determination at step **306** is that the localized region does not align with the sampling probe, the method **300** further comprises repeating steps **304** and **306** until the localized region does align with the sampling probe. FIG. **3**E illustrates this repeated punching process, in which gun charges **228** punch the formation **200** such that the localized region **312** increases in size until it aligns with the fluid sampling probe **212**, as dashed line **314** indicates.

When the result of the determination at step **306** is that the localized region aligns with the sampling probe, the method **300** comprises sampling the formation fluid (step **308**). FIG. **3**F illustrates such sampling, in which the sealing pad **210** extends away from the tool assembly **201** and toward the borehole wall **202** until it forms a seal with the wall **202**. In some embodiments, rams (not specifically shown) are extended from the opposite side of the tool assembly so that the pad **210** is forced into a sealing contact with the borehole wall **202**. The probe **212** then samples the fluid as described above. In this way, the tool assembly **201** increases the size of the localized region **312** until the region is accessible to the sampling probe **212**, thereby making it unnecessary to reposition the tool assembly **201** to align the probe **212** and localized region **312**.

In some embodiments, however, the tool assembly **201** may be repositioned in lieu of repeated punching—for instance, in cases where additional punching would negatively affect the integrity of the borehole wall **202**. FIG. **4**A shows an illustrative method **400** for increasing formation permeability in accordance with such embodiments. Processing logic (e.g., one or more of processing logic **203**, **205** and/or **207**) performs the method **400** during the drilling process, meaning that the steps of method **400** may be performed when the drill bit **114** (FIG. **1**) is operational, during periods when the drill bit **114** is temporarily stopped, or both. Method **400** is now described in light of FIGS. **4**B-**4**F, which constitute an illustrative implementation of the method **400**. The method **400** begins by identifying a target area of the borehole wall (step **402**). FIG. **4**B illustrates the target area using numeral **412**. The method **400** further comprises punching the target area **412** (step **404**). FIG. **4**C illustrates the gun charges **228** of punching tool **211** punching the target area to produce localized region **414**. As explained, the localized region **414** is the area of the formation that increases in permeability due to the punching tool **211**.

Method **400** then comprises determining whether the localized region **414** aligns with the fluid sampling probe **212** (step **406**). In some embodiments, whether a probe and a localized region are aligned depends on whether one or more fissures in the localized region are sufficiently close to the borehole wall **202** so that the fluid is accessible to the sampling probe. Sensor **226** performs this detection step using any of a variety of known techniques to identify the spatial features of the fissures (e.g., length, width, height, position, direction, concentration, total number, average volume, and/or total volume) in the localized region **414**.

FIG. **4**D illustrates the case in which the localized region **414** does not align with the fluid sampling probe **212**, as dashed line **416** denotes. In such cases, the method **400** comprises repositioning the fluid sampling probe **212** (step **410**). FIG. **4**E illustrates such a repositioning of the probe **212**, in which the entire tool assembly **201**—that is, the drill string itself—is repositioned within the borehole **112** such that the probe **212** aligns with the localized region **414**, as dashed line **416** denotes. Step **410** is performed in lieu of repeated punching of the target area. In some embodiments, the fluid sampling probe **212** is repositioned by a distance less than that between the position of the probe **212** (i.e., prior to repositioning) and the punching tool **211**. Stated another way, in some embodiments, the fluid sampling probe **212** is repositioned by the minimum distance necessary for the probe **212** to access fluid-containing fissures in the localized region **414**.

Regardless of the determination at step **406**, the method **400** concludes by sampling the formation fluid (step **408**). FIG. **4**F illustrates such sampling, in which the sealing pad **210** is extended away from the tool assembly **201** and toward the borehole wall **202** until the pad forms a seal with the wall **202**. Rams are optionally used to enhance the seal, as described above with respect to method **300**. The fluid sampling probe **212** then samples fluid as described above.

Some embodiments comprise both the repeated punching of the borehole wall as well as the repositioning of the tool assembly. Generally, in such embodiments, the greater the number and/or force of punches delivered to the formation, the greater the size of the fissured, localized region and the smaller the distance that the tool assembly must subsequently be repositioned to ensure alignment of the fluid sampling probe and the localized region.

Numerous other variations and modifications will become apparent to those skilled in the art once the above disclosure is fully appreciated. For example, the steps shown in methods **300** and **400** are merely illustrative, and various additions, deletions and other modifications may be made as desired and appropriate. Moreover, the systems and methods disclosed herein may be used to obtain additional, useful information. For instance, processing logic may compare the force with which a punching tool **211** punches a borehole wall **202** to the increase in permeability in the punched area (e.g., as determined by sensor **226**) to draw conclusions about the formation at the site of punching—for instance, to determine a permeability level relative to other, similarly punched areas. Similarly, the illustrative implementations described herein (e.g., with respect to FIG. **1**) are merely exemplary; any and all other such implementations also fall within the scope of this disclosure. It is intended that the following claims be interpreted to embrace all such variations, modifications and equivalents. In addition, the term "or" should be interpreted in an inclusive sense.

The present disclosure encompasses numerous embodiments. At least some of these embodiments are directed to a drill string tool assembly that comprises a punching tool that induces fissures to increase permeability in a localized region of a borehole wall. The assembly also comprises a sensor that detects spatial features of the fissures and processing logic, coupled to the sensor and punching tool, that adapts operation of the punching tool based on the spatial features. The assembly further comprises a fluid sampling probe, coupled to the processing logic, that samples fluid from the localized region.

In addition, at least some of the embodiments are directed to a method that comprises punching a formation to create fissures in a localized portion of the formation until at least one of the fissures aligns with a fluid sampling probe, sampling formation fluid from the localized portion, and storing the formation fluid in a drill string tool assembly.

Further, at least some of the embodiments are directed to a method that comprises punching a borehole wall to create fissures in a localized region of a formation, sensing spatial features of the localized region, and using the spatial features to adjust a position of a fluid sampling probe such that the probe is aligned with the localized region.

The foregoing embodiments may be supplemented in any of a variety of ways, including by adding any of the following, in any sequence and in any combination: The drill string tool assembly processing logic determines when the fluid sampling probe is aligned with the localized region and triggers operation of the fluid sampling probe when it is so aligned. The drill string tool assembly processing logic repositions the tool assembly to align the fluid sampling probe with the localized region. The drill string tool assembly sensor is selected from the group consisting of a fiber optic sensor and an electromagnetic sensor. The drill string tool assembly is contained within a single drill string sub. The drill string tool assembly punching tool is selected from the group consisting of a perforation gun, a laser, a steam jet, a fluid jet, a heating device, a hydraulic ram and a hammer. The drill string tool assembly punching tool induces fissures during a drilling operation, and the fluid sampling probe also samples the fluid during the drilling operation. The methods may further comprise determining properties associated with the localized portion by considering a force with which the formation is punched. The methods may comprise using either a fiber optic sensor or an electromagnetic sensor to punch the formation until at least one of the fissures aligns with the fluid sampling probe. In at least some of the methods, the drill string tool assembly is contained within a single drill string sub. In at least some of the methods, the punching comprises using a tool selected from the group consisting of a perforation gun, a laser, a steam jet, a fluid jet, a heating device, a hydraulic ram and a hammer. The methods may further comprise performing the punching and the sampling during a drilling operation. In at least some of the methods, adjusting the position of the fluid sampling probe comprises re-positioning the probe by a distance less than that between the probe and a punching tool used for the punching. In at least some of the methods, sensing comprises using either a fiber optic sensor or an electromagnetic sensor. At least some of the methods further comprise housing the fluid sampling probe and a punching tool used for the punching within a single drill string sub. At least some of the methods further comprise sampling fluid from the localized region during a drilling operation. At least some of the methods further comprise again punching the borehole wall to increase a size of the localized region.

The following is claimed:

1. A drill string tool assembly, comprising:

a punching tool that induces fissures to increase permeability in a localized region of a borehole wall;

a sensor that detects spatial features of the fissures;

processing logic, coupled to the sensor and punching tool, that adapts operation of the punching tool based on said spatial features; and

a fluid sampling probe, coupled to the processing logic, that samples fluid from the localized region.

2. The drill string tool assembly of claim **1**, wherein the processing logic determines when the fluid sampling probe is aligned with the localized region and triggers operation of the fluid sampling probe when it is so aligned.

3. The drill string tool assembly of claim **1**, wherein the processing logic repositions the tool assembly to align the fluid sampling probe with the localized region.

4. The drill string tool assembly of claim **1**, wherein the sensor is selected from the group consisting of a fiber optic sensor and an electromagnetic sensor.

5. The drill string tool assembly of claim **1**, wherein the drill string tool assembly is contained within a single drill string sub.

6. The drill string tool assembly of claim **1**, wherein the punching tool is selected from the group consisting of a perforation gun, a laser, a steam jet, a fluid jet, a heating device, a hydraulic ram and a hammer.

7. The drill string tool assembly of claim **1**, wherein the punching tool induces said fissures during a drilling operation, and wherein the fluid sampling probe also samples the fluid during said drilling operation.

8. A method, comprising:

punching a formation to create fissures in a localized portion of the formation until at least one of said fissures aligns with a fluid sampling probe;

sampling formation fluid from the localized portion; and

storing said formation fluid in a drill string tool assembly.

9. The method of claim **8**, further comprising determining properties associated with the localized portion by considering a force with which the formation is punched.

10. The method of claim **8**, wherein punching the formation until at least one of said fissures aligns with the fluid sampling probe comprises using either a fiber optic sensor or an electromagnetic sensor.

11. The method of claim **8**, wherein the drill string tool assembly is contained within a single drill string sub.

12. The method of claim **8**, wherein said punching comprises using a tool selected from the group consisting of a perforation gun, a laser, a steam jet, a fluid jet, a heating device, a hydraulic ram and a hammer.

13. The method of claim **8**, further comprising performing said punching and said sampling during a drilling operation.

14. A method, comprising:

punching a borehole wall to create fissures in a localized region of a formation;

sensing spatial features of the localized region; and

using the spatial features to adjust a position of a fluid sampling probe such that the probe is aligned with the localized region.

15. The method of claim **14**, wherein adjusting said position comprises re-positioning the probe by a distance less than that between the probe and a punching tool used for said punching.

16. The method of claim **14**, further comprising comparing a force used to punch said borehole wall with said sensed spatial features to determine information about said localized region.

17. The method of claim **14**, wherein said sensing comprises using either a fiber optic sensor or an electromagnetic sensor.

18. The method of claim **14**, further comprising housing the fluid sampling probe and a punching tool used for said punching within a single drill string sub.

19. The method of claim **14**, further comprising sampling fluid from the localized region during a drilling operation.

20. The method of claim **14**, further comprising again punching the borehole wall to increase a size of the localized region.

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